# STATISTICS ON THE MOVEMENT AND DEEPENING OF CYCLONES IN THE MIDDLE WEST

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ABSTRACT

The inter-relations of intensity, speed, and direction of movement of cyclones in the central United States are investigated. Evidence is developed concerning the validity of several forecasting rules relating to the movement of cyclones.

## INTRODUCTION

The objective of this investigation was to evaluate some of the forecasting rules which relate to the interdependence of cyclone intensity, direction of movement, and speed. Particular attention was given to rules concerning the tendency of cyclones to intensify when moving to the left of a normal course [1], and the corollary tendency to decrease or fill when moving to the south or southeast. Although rules such as these are not explicitly utilized in present-day forecasting to the same extent as formerly, they nonetheless influence the forecast from the subjective side since the experience and empirical knowledge of the forecaster tend to be formulated in such terms. An objective assessment of these rules therefore appears desirable.

The plan of attack consisted of correlating the *direction* taken by various cyclones with: (1) the initial pressure of the cyclone center; (2) the 12-hour change in central pressure; and, (3) the distance moved in the subsequent 12 hours. In addition, the *distance* cyclones moved in 12 hours was compared with: (4) the 12-hour change in central pressure and, (5) the initial pressure of the low center.

The procedure for obtaining these data was relatively free of bias since the source material, storm tracks from the *Monthly Weather Review* from 1920 to 1929, inclusive, gives not only the storm track but the central pressure at 12-hour intervals. For items (1) to (3) direction was divided into octants, the first extending from 1° to 45°, the second from 46° to 90°, and so on. The pressure given at the beginning of each 12-hour track, the distance moved in the subsequent 12 hours, and the change in pressure during the 12 hours were each tabulated in appropriate direction categories.

For item (4) a similar procedure was followed with pressure change ordered into nine categories, the central category representing zero change and those on either side increasing by steps of .10 inch in 12 hours with the first and last category reserved for changes in excess of .30 inch, minus and plus respectively. The same method was used for item (5) with the central pressure of the cyclones ordered into six categories, the first including all those less than 29.20 inches, and the last those above 29.99, with the four intervening categories each subtending .20 inch.

The data were tabulated separately for summer, winter, and all year. Summer in this study was arbitrarily defined as the five months extending from May through September and winter the period from November through March. October and April were omitted from both seasons (but, of course, are included in the all year data) due to the considerable range of latitude within the defined area. Along the Gulf of Mexico these months are more nearly characteristic of the summer season while at the Canadian border they would usually be included in the colder half of the year. A division into the four standard seasons would have been preferable but the data were not sufficiently numerous to support the additional subdivisions.

The decade of the 1920's was chosen as the base for this study for two reasons. First, larger scale charts were used prior to 1930 for showing the cyclone tracks, permitting greater accuracy in scaling off the distances; and second, these charts give the central pressure of each cyclone for both 0700 and 1900 CST while the charts since 1930 give only the 0700 CST pressure. The 12-hour interval is, of course, preferable where the relation of direction to other variables is the subject of interest. The choice of this decade entails some loss of accuracy as compared with more recent years due to the sparser station network of that time.

The area studied was restricted to that portion of the central United States bounded by the 85th and 100th meridians between the parallels of 30° and 50° N. None of the ground within this area exceeds 3,000 feet in elevation so that sea level pressures may be used with reasonable confidence. Many of the poorly defined Lows in the lee of the Rockies are also excluded by this choice. All of the tracks within this area were included in the summary with the exception of a few for which the central pressure of the cyclone was not recorded. One hurricane which moved into the area in 1926 and filled very rapidly was also excluded. A total of 2,177 12-hour tracks was summarized. Although the *Monthly Weather Review* charts show the cyclone tracks as smooth curves, the 12-hour segments were, for this study, assumed to be straight lines.

The source material and the methods of extracting the data impair the accuracy of the results in some respects. The monthly cyclone tracks are published on relatively small-scale charts so that distances had to be scaled off to the nearest ten miles. The circles used to show the location of the centers were never drawn as overlapping and were of such size that the shortest 12-hour movement that could be shown, measuring from center to center, was approximately 60 miles. A third element of error arose in determining the direction of the tracks. The octants into which direction was divided were found by bisecting the angles formed by meridians and parallels by straight lines. On a chart of conic section where latitude is shown as curved lines, a straight line bisector does not define true octants. For the range of distances included in this study the error attributable to this cause is not much greater than that involved in locating the center of a cyclone and it affects only those tracks along the boundary of the octants.

## CENTRAL PRESSURE VS. DIRECTION OF MOVEMENT

Figure 1 shows the average pressure of cyclones plotted against the subsequent direction of motion. The curves for winter and for the year as a whole both show progressively higher mean central pressures corresponding to the shift in direction from north-northeast to south-southeast. In winter, for example, the average pressure for all storms that moved north-northeast in the subsequent 12 hours was 29.55 inches, the average for those moving east-northeast was 29.66, those moving east-southeast 29.68, and those directed south-southeast averaged out at 29.73 inches. The graph for the year as a whole has the same trend over this range of direction but with a somewhat smaller and more uniform increase in pressure corresponding to the increasing southward deflection of the cyclone tracks. This trend is supported by so considerable a mass of data that it can hardly be dismissed as coincidental even though those summer storms moving north-northeast fail to fit the general picture. Curves for winter conditions were omitted for the octants SSW through NNW in figure 1 (and also in figs. 2, 3, 4, and 5) as there were a total of only four cases showing movement to the west. Less than three percent of the data for the entire decade fell within these octants, so not much weight can be assigned even to those curves that are shown for westward-moving storms.

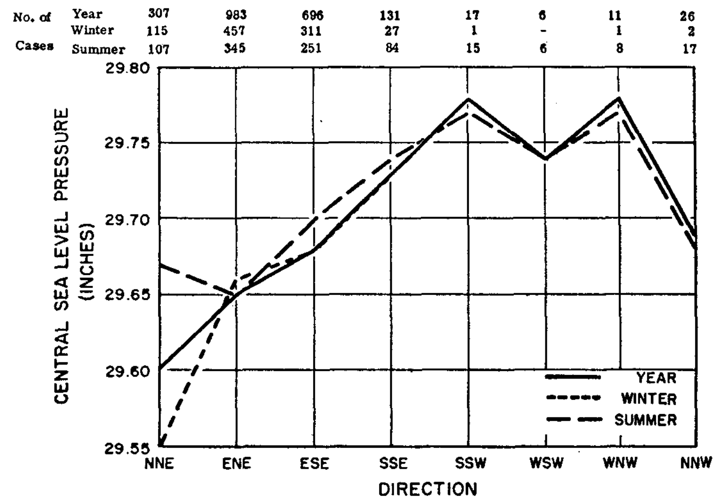


FIGURE 1.—Mean central sea level pressure of cyclones plotted against direction toward which they moved in subsequent 12 hours. Number of cases falling into each octant is shown across top of graph. Summer includes May through September; winter, November through March.

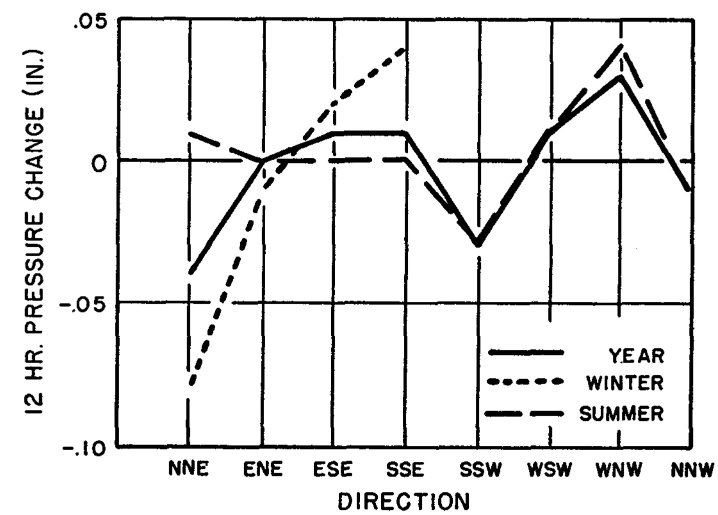


FIGURE 2.—Mean net change in central pressure in 12 hours plotted against direction of movement of cyclones. The number of cases for each direction is the same as in figure 1.

It will be noted from the frequency table accompanying figure 1 that storms moving east-northeast represent a high percentage of the total. This direction, which may be taken as approximately the mean, or normal, direction for cyclones included in this study, shows very little seasonal variation in central pressure. Those storms moving to the left of this course are of greater than average intensity, assuming that central pressure is an index of intensity, while those of less intensity are deflected to the south with the greatest deflection corresponding to the least intensity.

## 12-HOUR PRESSURE CHANGE VS. DIRECTION OF MOVEMENT

Figure 2 shows the mean net change of central pressure for 12 hours plotted against direction of cyclone movement. The mean net change for a given direction is the algebraic mean of *all* cases in that direction category. Where

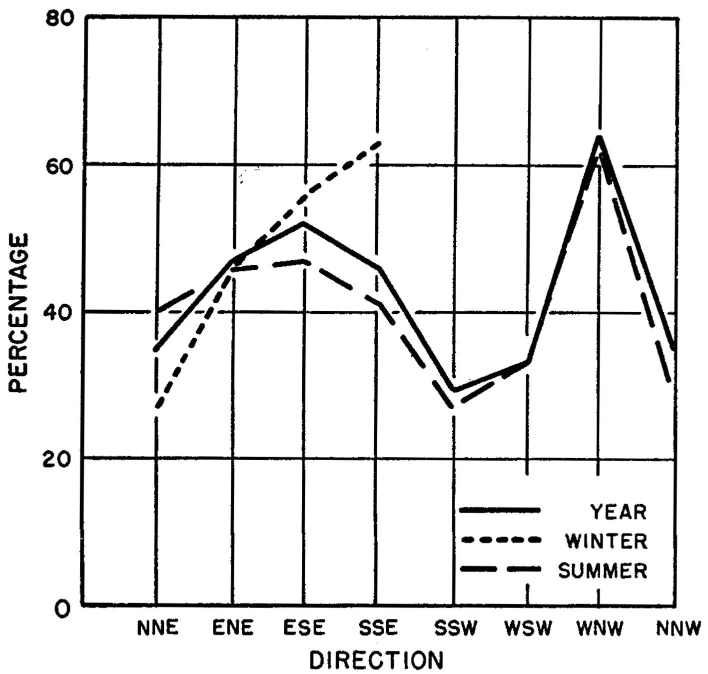


FIGURE 3.—Percentage of cyclones showing positive 12-hour pressure change plotted against direction of cyclone movement.

direction is neutral, or without influence on intensification of cyclones, the rise and fall of central pressure should balance out if a large enough number of cyclones is considered. Figure 2 shows that east-northeast is such a neutral direction. Net pressure change is zero when all storms are considered and very nearly zero even for winter cyclones. Figure 3 confirms this conclusion indicating about an even probability for either rising or falling pressure on this track.

The influence of direction on intensification becomes apparent only when cyclones deviate from this east-northeasterly track. The correlation is not striking for summer cyclones but the consistency of the curve for winter conditions in figure 2 is noteworthy. For storms moving north-northeast, 69 percent showed falling pressure with an average decrease of .15 inch in 12 hours. The average net change in pressure for all storms moving in this direction was −.08 inch in 12 hours. Saucier [4] found a similar relation between pressure change and direction in his study of Texas cyclones.

The winter cyclones moving south of east showed an increasing tendency for rising central pressure culminating in a 12-hour average net rise of .04 inch for those moving south-southeast; 63 percent of the 27 cyclones sharing this direction were characterized by rising central pressure.

The similarity of the curves for figures 1 and 2 is, of course, not accidental since the change of pressure dealt with in figure 2 contributes to variation in central pressure considered in figure 1.

## SPEED VS. DIRECTION OF MOVEMENT

Figure 4 is designed to reveal any correlation that may exist between the direction a cyclone takes and the speed

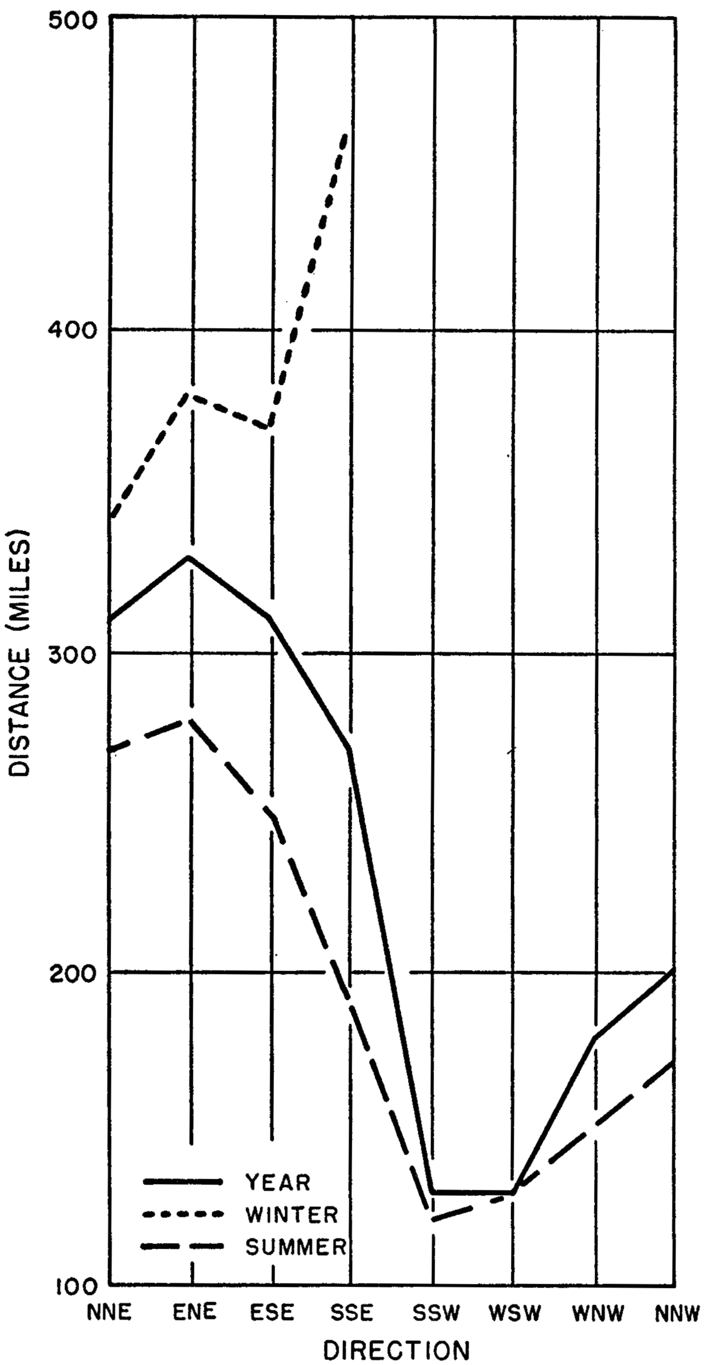


FIGURE 4.—Average distance traversed by cyclones in 12 hours plotted against direction of movement. The number of cases for each direction is the same as in figure 1.

with which it moves. Figure 5, which shows the percentage absolute mean deviation from the average distances plotted in figure 4, serves the usual purpose in providing a measure of the variability of the data from which the averages are derived. The minimum mean deviation in the first four octants, where the bulk of the data is concentrated, is for cyclones moving east-southeast in winter and amounts to plus or minus 123 miles from an average of 370 miles. Expressed in percentage the minimum absolute deviation for any of these four direction categories is 33 percent, the maximum 54 percent, and the

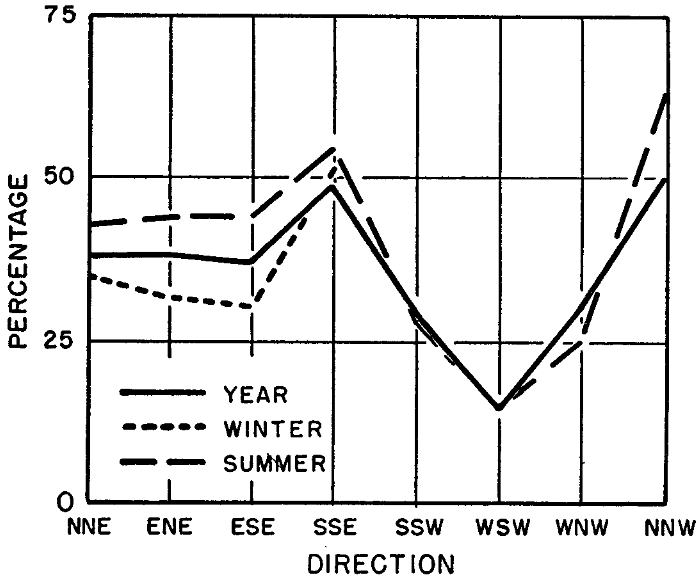


FIGURE 5.—Percentage absolute mean deviation of 12-hour distance traversed by cyclones plotted against direction of movement.

average near 40 percent. These deviations exceed most of the seasonal differences in speed of cyclones revealed in figure 4. Where such high absolute mean deviations are encountered, a relatively low order of verification must be expected of forecast rules relating speed and direction of motion of cyclones.

With these reservations in mind, figure 4 still has some points of interest. The maximum revealed by the curves for storms moving east-northeast is not of great magnitude but it is conspicuous for its persistence throughout the year. The distribution of data supports the assumption that this maximum is real and comprises, in effect, a path of least resistance for cyclones. Not only do storms move faster on this track, they are also more numerous. Forty-five percent of all Middle West cyclones in the decade of the 1920's moved east-northeast. The predominant direction of cyclones off the east coast of the United States is shown by Miller [3] to fall within this octant and Saucier [4] confirms this conclusion for Texas cyclones.

## SPEED OF MOVEMENT VS. 12-HOUR PRESSURE CHANGE

Figures 6 and 7 deal with the influence of changing pressure on the speed of cyclone movement. Before discussing these graphs, it would be worth noting from the frequency table at the top of figure 6 that the cases fall into a remarkably symmetrical pattern, a distribution quite different from that of the preceding figures.

The relation between change in central pressure and distance travelled in 12 hours, illustrated in figure 6, has several points of interest. The curves for both summer and winter indicate that rapidly deepening storms move rapidly, with the greater speed associated with the larger pressure falls. The curve for all year, which includes April and October data in addition to those of summer and winter, emphasizes this conclusion. The storms of

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of Cases | Year | 19 | 53 | 238 | 688 | 172 | 713 | 234 | 52 | 8 |
| | Winter | 15 | 41 | 125 | 230 | 67 | 286 | 115 | 30 | 5 |
| | Summer | 1 | 3 | 75 | 313 | 67 | 290 | 73 | 10 | 1 |

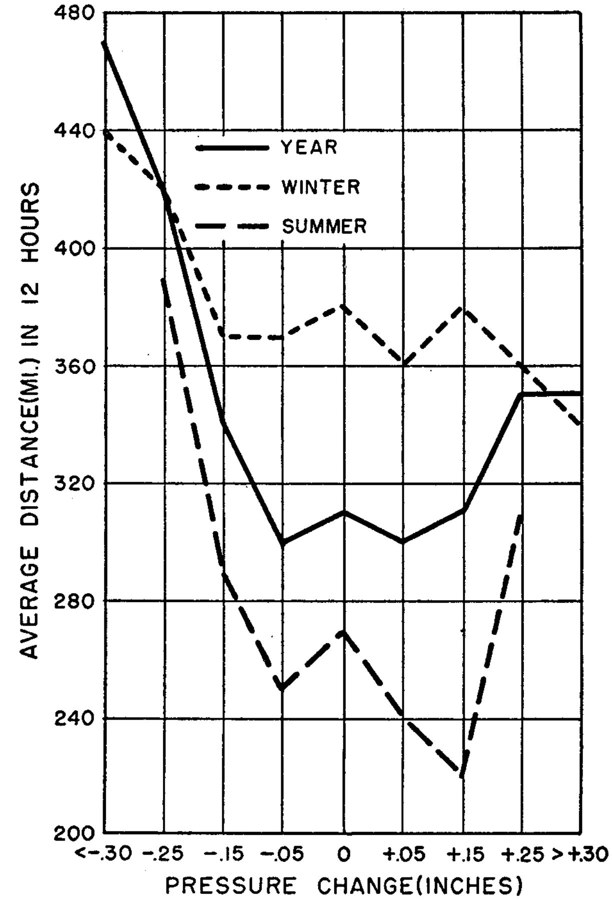


FIGURE 6.—Average 12-hour distance traversed by cyclones plotted against change in central pressure. Number of cases in each category is shown in table across top of graph.

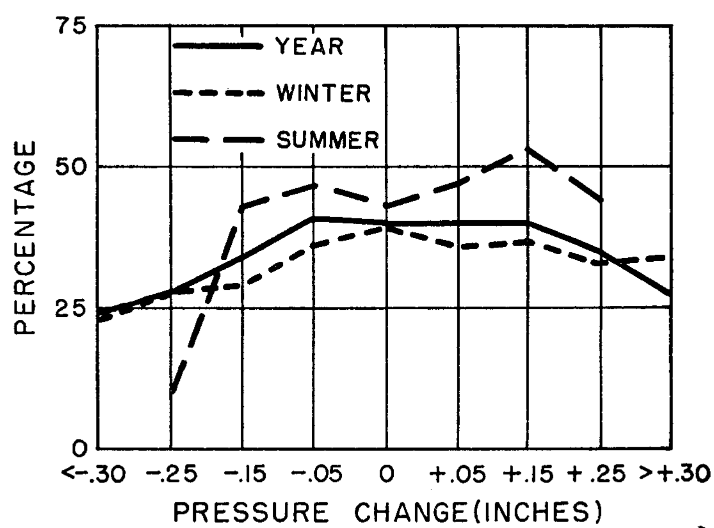


FIGURE 7.—Percentage absolute mean deviation of 12-hour distance traversed by cyclones plotted against change in central pressure.

rapidly increasing central pressure display such a considerable variation between winter and summer that no general conclusions appear justified. The pattern of all three curves is similar throughout the area of falling pressure and this consistency extends into the first interval of rising pressure. The only exception to this pattern is found in the data for April and October which show a minimum speed at zero pressure change in place of the lesser speed on either side of zero characteristic of the other seasons.

Figure 7, where the percentage absolute mean deviations from the averages plotted in figure 6 are shown, resembles figure 5 in the general magnitude of the deviations. There is apparently a tendency for greater consistency of movement to be found in cyclones undergoing rapid pressure changes in either direction. The storms of the winter season show less variation in speed than those of summer.

## SPEED OF MOVEMENT VS. CENTRAL PRESSURE

Figures 8 and 9 show the relation between initial central pressure of cyclones and speed expressed as distance traveled per half day. As shown in the frequency table at the top of figure 8 most of the data are clustered around the 29.70-inch category, 41 percent of all cyclones falling within the .20-inch interval centered on this value. The 29.50-inch category contains 23 percent of the data, the 29.90-inch category 24 percent, the 29.30-inch category 7 percent, and the 29.20-inch category only 2 percent.

The frequency distribution for winter and for April and October are similar to the year as a whole. Summer cyclones were of less intensity with 78 percent above the 29.60-inch mark.

The most noteworthy feature of figure 8 is the divergence of the summer and winter curves. The most intense storms of winter show the generally acknowledged inverse relation between speed and intensity but those of summer show an opposite tendency—the deeper storms moving more rapidly on the average throughout the range of intensity. The usefulness of the latter conclusion is qualified, however, by the much higher mean deviations characteristic of summer cyclones. As figure 9 indicates, the absolute mean deviation is 47 percent or greater for summer cyclones of central pressure greater than 29.60 inches and, as pointed out above, 78 percent of summer cyclones fall in this range.

Winter storms of all intensities move more consistently than those of summer, with the deeper Lows showing some-

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| No. of Cases | Year | 40 | 166 | 488 | 902 | 521 | 60 |
| | Winter | 29 | 88 | 209 | 322 | 219 | 47 |
| | Summer | 5 | 30 | 155 | 416 | 222 | 5 |

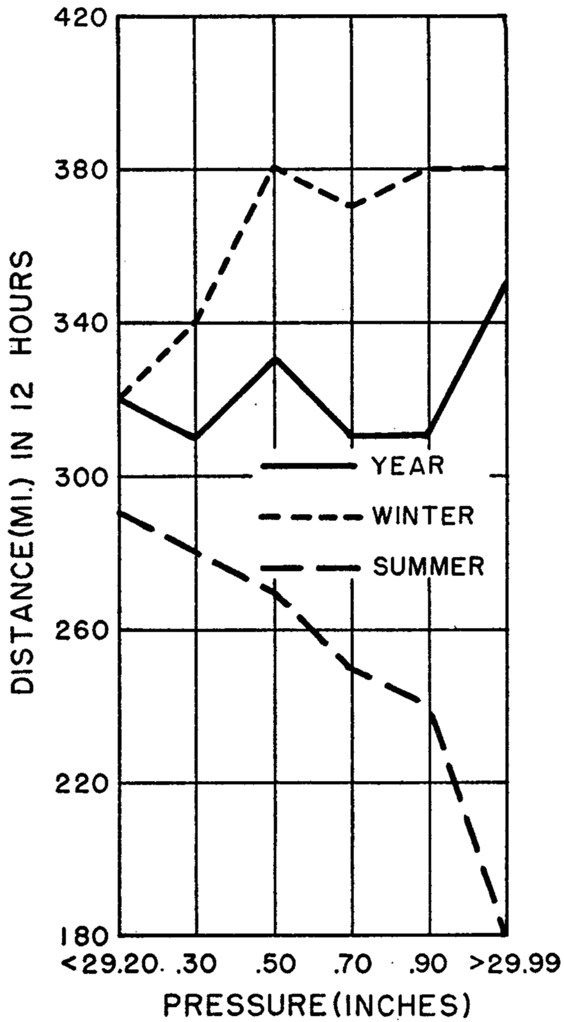


FIGURE 8.—Distance traversed in 12 hours plotted against initial central pressure of cyclones. Number of cases falling in each pressure interval is shown in table across top of graph.

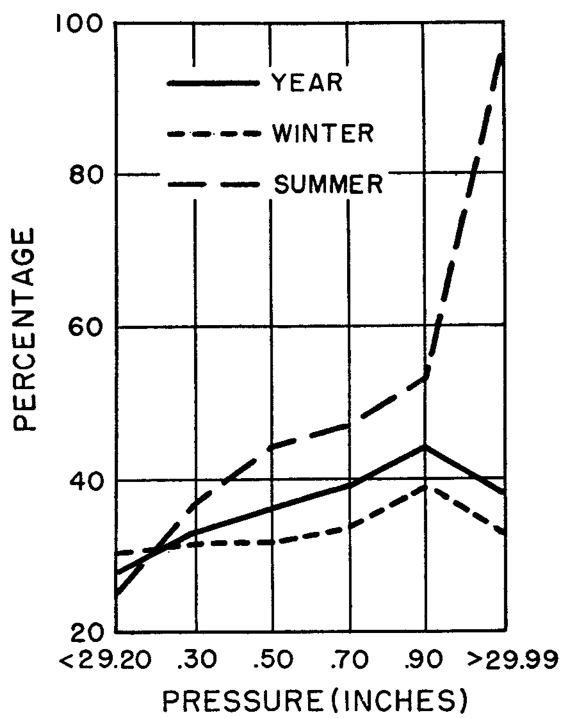


FIGURE 9.—Percentage absolute mean deviation of distance traversed in 12 hours plotted against initial central pressure of cyclones.

what smaller deviation than those of slight intensity. Referring to figure 9 again, it will be noticed that the mean deviation expressed in percent increases from 30 for the most intense winter storms to 39 for those averaging 29.90 inches.

## MONTHLY FREQUENCY OF CYCLONES

Considering the frequency of cyclone tracks of all intensities, figure 10 reveals a maximum in April and a secondary maximum in October. When only those storms with a central pressure less than 29.60 inches are considered, the April maximum retains its prominence but the December frequency becomes greater than that of October. Miller [3] found a maximum frequency of east coast cyclones in December and March while his winter minimum occurred in February as compared with the January minimum for Middle West cyclones. This difference of minimum frequency must reflect the influence of the Atlantic coast, as a division of the Middle West cyclones into those south of latitude 40° N. and those north of it shows the January minimum common to both. Those cyclone tracks south of 40° N. display a much greater seasonal variation with the fall maximum in December in contrast to a well-defined October maximum for those tracks north of 40° N.

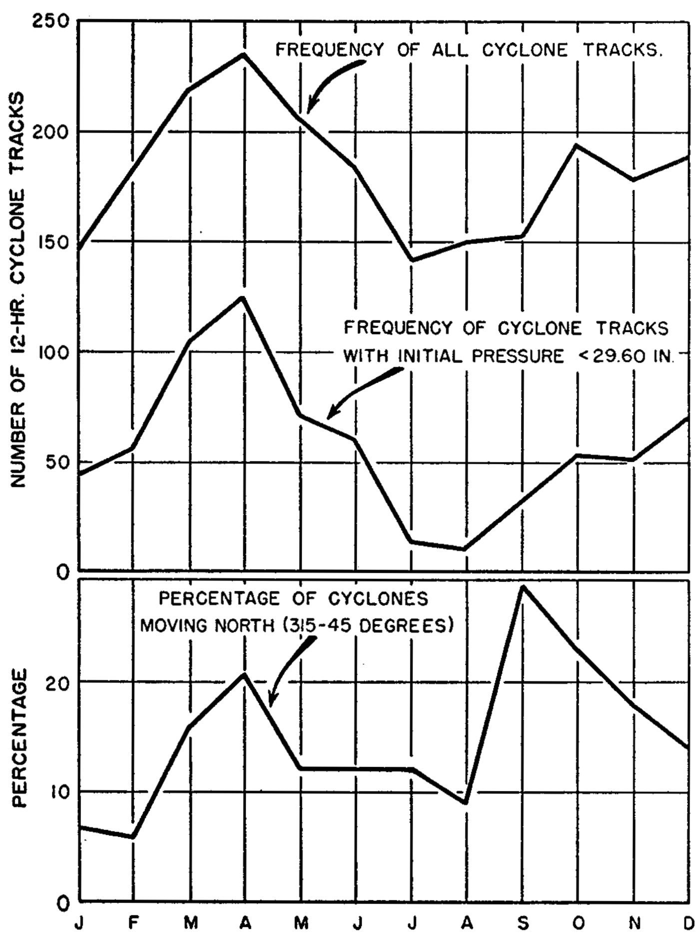


FIGURE 10.—Frequency of 12-hour cyclone tracks by months.

The frequency curve of northward moving cyclones also has spring and fall maxima but the September peak in this case is clearly dominant. This curve very likely reflects a preponderance of Texas cyclones, as Weightman [2] shows a corresponding northward deflection of Texas cyclones most conspicuous during September and October in the Middle West. Weightman's average tracks for late winter show a less marked northerly course for Lows, with the greatest northward deflection during February and March—the former month representing a minimum for this study.

## DISCUSSION OF RESULTS IN RELATION TO FORECASTING RULES

The evidence adduced from this investigation bears on the forecasting rules listed hereunder. The premise, common to most statistical studies, that long-term changes in the atmosphere are of insufficient magnitude to affect the relation between the recent past and the near future applies, of course, to this study also. The lack of agreement between the results of this study and some forecast rules may possibly be attributed to this assumption.

1. Usually a storm that moves to the left of a normal track increases in intensity [1].

Assuming that the normal, or most frequent track for this area as a whole is east-northeast, 69 percent of winter storms moving to the left of normal exhibited this tendency with an average decrease in central pressure of .15 inch in 12 hours. The average net fall for all winter storms moving in the direction east-northeast was .08 inch in 12 hours.

2. *Storms that* start in the northwest and *move southeastward do not gather great intensity* until they begin to curve northward [1].

Referring to the italicized part of this rule, figure 3 shows that 56 percent of winter storms moving east-southeast display rising central pressure and 63 percent of those moving south-southeast exhibit a similar tendency.

3. Lows moving south of east move rapidly. The slowest moving Lows are those that have a tendency to move directly northward [1].

Figure 4 shows the first part of this rule to be true of winter conditions but the contrary holds for summer. The second part is also characteristic of winter but a similar relation does not exist for summer.

4. Deep Lows and Highs, i. e. those with closed isobars extending to 10,000 feet or more, move slowly or remain stationary [5].

Assuming that most intense Lows of the Middle West are cold Lows extending to considerable heights, figures 8 and 9 reveal that the difference in speed of deep winter Lows and those of slight or moderate intensity amounts to only 60 miles per half day while the absolute mean deviation of these same cyclones varies from 95 miles for those of less than 29.20 inches of central pressure to a maximum of 150 miles for those of less intensity. The evidence indicates that this rule is of marginal utility in winter and could be reversed to good advantage in summer.

5. Cyclonic centers that are exposed to cyclogenesis, or deepening, are usually retarded, and cyclonic centers that are exposed to cyclolysis, or filling, are usually accelerated [5].

Figure 6 shows, for the decade of the 1920's, that rapidly deepening cyclones move with considerably greater speed than those associated with any other change in central pressure. Although the term "retarded" used in the first part of the rule is an acceleration term not directly comparable to the speeds treated in this study, it can still be inferred with considerable assurance that deepening cyclones are more likely to be accelerated than retarded. The behavior of filling cyclones is shown to be more erratic although some evidence of acceleration is apparent.

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